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**SOME PHYSICAL PROPERTIES OF ENAMELS DEVELOPED
FOR USE AT HIGH TEMPERATURES ON SEVERAL
NONSTRATEGIC STEELS**

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THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION

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**SOME PHYSICAL PROPERTIES OF ENAMELS DEVELOPED
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FOREWORD

This report, No. 67, for Ohio State University Research Foundation, Project No. 341, was prepared under USAF Contract No. 33-038 ac-14217. The contract was initiated under the research and development project identified by Expenditure Order No. R-506-67, Ceramic Components for Aircraft Power Plants; it was administered under the direction of the Power Plant Laboratory, Aeronautics Division, Wright Air Development Center, with Lt. Col. R. A. Jones acting as project engineer.

ABSTRACT

This report covers results of tests made to determine the protective value at high temperatures of six enamels applied to a group of nonstrategic steels being investigated as possible substitute materials for stainless steel or Inconel in jet-propelled engines or other devices.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDING GENERAL:



NORMAN C. APPOLD
Colonel, USAF
Chief, Power Plant Laboratory
Aeronautics Division

SUMMARY

Six enamels selected from the group covered in Report No. 63 for this same project, and which had shown promise when applied to enameling iron, were applied to several non-strategic irons or steels.

The enamels selected were 252-4g, 252-4t, 252-4ah, 252-4as, 252-4au, and 252-4av. The metals were Ingot Iron, 1010 steel, a molybdenum steel, two high manganese steels, a titanium-boron steel, a titanium-bearing enameling steel "Ti-Namel", and a stainless-clad steel.

The enameled specimens were subjected to adherence and thermal-shock tests. The adherence tests were carried out according to a recent procedure developed and published by the Porcelain Enamel Institute in its Bulletin T-17.

The procedure for the thermal shock test was a slight modification of the standard procedure for enamels which has been described in detail in our previous reports.

Following are the conclusions based on these tests.

1. Adhesion Tests.

Using the average adhesion of these enamels to Ingot Iron shown in Table III, as the basis for comparison, the relative results were as follows.

(a) Adhesion with respect to Ti-Namel and RL steel was poor.

(b) Adhesion with respect to Ingot Iron, 1010 steel, RB steel, and Mo. steel was fair.

(c) Adhesion with respect to stainless-clad and titanium-boron steels was good.

2. Thermal Shock Tests.

(a) Resistance to thermal shock in the case of stainless-clad was good with all enamels except 252-4av.

(b) Resistance in the case of Ti-Namel was good with 252-4t and 252-4au but poor with all others.

(c) Resistance in the case of Mo. steel was fair with all enamels except 252-4av.

(d) Resistance in the case of titanium-boron steel was good with 252-4t, fair with 252-4au and 252-4ah, and poor with all others.

(e) Resistance in the case of Ingot Iron was good with 252-4t and 252-4as and poor with all others.

(f) Resistance in the case of 1010 steel was good with 252-4t only.

(g) Resistance of enamel 252-4t was good on all metals; of 252-4au, 252-4ah, and 252-4as was fair on all metals; of 252-4g and 252-4av was uniformly poor on all metals except that 252-4g was good on stainless steel.

1. ENAMELS

TABLE I

The compositions of the frits are as follows:

	Bureau of Standards Frit No. 11	Ohio State University Frit No. 252-2
Feldspar (Buckingham potash)	31.0	43.0
Quartz	18.0	25.0
Borax	37.1	20.0
Sodium Carbonate	5.9	----
Sodium Nitrate	3.8	4.0
Fluorspar	3.0	4.0
Co ₃ O ₄	0.5	1.0
NiO	0.6	1.0
MnO ₂	1.1	2.0

The compositions of the mill charges are as follows:

Enamel Code No.	252-4g	252-4t	252-4ah	252-4as	252-4au	252-4av
Frit No. 11	50.00	50.00	50.00	50.00	50.00	50.00
Frit No. 252-2	50.00	50.00	50.00	50.00	50.00	50.00
X-Brand Clay	7.00	7.00	7.00	7.00	7.00	7.00
Sodium nitrite	0.23	0.23	0.23	0.23	0.23	0.23
Water	50.00	50.00	50.00	50.00	50.00	50.00
Spodumene	10.00	-----	-----	-----	-----	3.33
Alumina	-----	10.00	-----	6.66	3.33	3.33
Titanium dioxide	-----	-----	10.00	3.33	6.66	3.33

2. STEELS

TABLE II

The partial compositions of the steels employed, together with the source are as follows;

Ingot Iron: Source - Armco Steel Corporation
Carbon 0.02%; copper not over 0.15%; total of silicon, sulphur, manganese, and phosphorus not over 0.14%.

RB Steel: Source - Armco Steel Corporation
Carbon less than 0.10%; manganese approx. 0.20%; sulphur 0.03%; silicon and phosphorus less than 0.01% each.

RL Steel: Source - Armco Steel Corporation
Carbon less than 0.10%; manganese approx. 0.33%;
sulphur 0.03%; silicon and phosphorus less than
0.01% each.

1010 Steel: Source - Republic Steel Corporation
Carbon 0.08 to 0.13%; manganese 0.30 to 0.60%;
phosphorus not over 0.04%.

Ti-Namel: Source - Inland Steel Corporation
Carbon 0.09% max.; manganese 0.50% max.; phosphorus
0.04% max.; sulphur 0.05% max.; silicon 0.10% max.;
titanium 0.20 to 0.50%.

Molybdenum Steel: Source - Carnegie-Illinois Steel Corporation
Carbon 0.12% max.; manganese 0.47%; phosphorus
0.023% max.; sulphur 0.021% max.; silicon 0.19% max.;
molybdenum 0.46%.

302 Stainless-Clad Steel (carbon-steel core): Source - Republic
Steel Corporation
Carbon 0.08 to 0.20% max.; chromium 17.0 to 19.0%;
nickel 7.0 to 9.0%.

Titanium-boron Steel: Source - Wright Air Development Center
Carbon 0.066% max.; manganese 0.054% max.; silicon
0.057% max.; chromium 2.27%; molybdenum 0.93%;
titanium 0.67%; boron 0.035%.

3. PREPARATION OF THE ENAMELS

(a) Smelting

Bureau of Standards Frit No. 11

The raw batch materials were weighed, screened three times through a 20 mesh sieve, thoroughly mixed and smelted at a temperature of approximately 2320°F. in about 55 - 60 minutes. Maturity of the enamel was indicated by the smooth surface of the melt and the smoothness of a thread of glass drawn from the melt. The melt was then fritted by pouring it into cold water. This frit was then dried thoroughly and milled to minus 40 mesh.

Ohio State University Frit No. 252-2

The procedure was identical to that given above with the exception that the firing temperature was approximately 2650°F. and the time was about 1 hour 20 minutes.

(b) Milling

Mill batches containing 400 grams of frit were weighed and loaded into porcelain ball mills of one quart capacity. Milling was continued until only 1% to 3% was retained on a 200 mesh sieve.

(c) Metal Preparation

Prior to sandblasting or pickling, the metal was degreased thoroughly by washing with perchlorethylene for best results. Sandblasting and pickling procedures were effected through the standard methods. For best results the stainless-clad steel, the molybdenum steel and the titanium-boron steel were sandblasted. The other metals were pickled satisfactorily according to conventional methods.

(d) Application of the Enamels.

These enamels were applied by dipping after the slip was adjusted by additions of water to a dry pick-up weight of from 37.8 to 41.4 grams on a steel plate one foot square (both sides being covered). This weight produced a fired enamel thickness of from 0.0035 to 0.0050 inches. For best results the metal surface was scrubbed with a diluted solution of the enamel prior to dipping. This practice removed any salts which may have clung to the metal from the neutralizing bath. After dipping

and proper draining the enamel was dried at 105°C.

(e) Firing

These enamels were fired in an electric furnace at 1700°F. for five minutes.

4. TESTS

(a) Adhesion Tests

The recently published tentative standard test of the Porcelain Enamel Institute was employed. This is described in Bulletin T-17 titled "Test for Adherence of Porcelain Enamel to Sheet Metal". The mechanical equipment previously used for the adherence test is shown in Figure 3 of Report No. 52 and is referenced in connection with this same test on page 4 of Report No. 63. Using this older method, a steel ball was forced against the enameled sheet-steel specimen to deform it and the evaluation of the result was made visually. For the test now adopted as standard by the Porcelain Enamel Institute, the machine used is called an adherence meter. It consists of two elements:

1. The enameled specimen sheet is deformed by a ball point as before, but under a standard hydraulic pressure.
2. Evaluation of the enamel removed is accomplished by bringing into contact with the deformed area 169 needle points held in the head of the machine. An electrical circuit is completed between this head and the enameled sheet at all points where any of the needles touch bare metal. A counter on the machine records the number of such electrical contacts. Therefore if the deformed area is completely bare of enamel the maximum reading of 169 is

recorded. Any reading lower than this indicates the amount of enamel still adhering to the deformed area. The needle count is used for evaluation.

TABLE III

Average Adhesion Values for All Steels and Enamels

Enamel Code No.	252-4as	252-4ah	252-4g	252-4t	252-4au	252-4av	Average
Stainless Clad	48.8	76.1	33.6	16.5	38.2	77.7	48.5
Ti-Namel	103.6	142.5	103.4	97.4	130.4	122.1	116.6
Ingot Iron	69.8	146.9	18.5	66.4	93.7	63.7	76.4
1010 Steel	84.8	96.2	31.8	48.2	102.1	125.9	81.5
RB Steel	86.3	150.8	63.4	91.5	87.1	68.4	91.2
RL Steel	111.0	125.7	51.2	105.5	147.5	82.0	103.8
Mo. Steel	73.2	144.3	45.5	95.4	99.6	116.1	95.6
Ti-B Steel	15.2	31.1	24.8	9.3	20.2	70.7	28.6
Average	74.1	114.2	46.5	66.2	89.8	90.8	

Note: The lower the index number the better the adherence. This table shows the actual counter readings on the Adherence Meter and are proportional to the highest possible reading of 169 as explained in the text.

(b) Thermal Shock Tests

Test specimens 2.0" x 4.0" were suspended vertically in a rack which was placed in an electric furnace and heated for fifteen minutes at 1400°F., after which the rack carrying the specimens was removed and placed in the air stream from a 12 inch office fan. This cycle was repeated for eight hours and then the specimens were heated in the furnace for sixteen hours at 1400°F. This eight-hour and sixteen-hour treatment was then repeated, thus making a total of sixteen hours of cycling and thirty-two hours of continuous heating. This treatment brought about some differentiation in the appearance of the surfaces as given in detail in the Summary.

5. RECOMMENDATIONS

Tests on combustion chamber liners and tail-cones of enameling iron coated with enamel 252-4as have been under way for sometime. Recently some Ti-Namel liners were coated with 252-4as and submitted for test. In view of the favorable showing of enamels 252-4t and 252-4au, and the metals Ingot Iron, Ti-Namel, molybdenum steel, and titanium-boron steel, it is recommended that extensive tests be carried out on parts made from these metals and coated with 252-4t, 252-4au, as well as 252-4as.

6. FUTURE PLANS

In addition to coating of actual parts, it is planned to do further research on these enamels with a view to improving their protective value.